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Predation of Juvenile Delta Smelt in the Bypass Pipes and Secondary Channel at the Tracy Fish Collection Facility

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California-Great Basin · Interior Region 10

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14. ABSTRACT
Fish loss due to predation negatively impacts fish salvage at the Bureau of Reclamation's Tracy Fish Collection Facility (TFCF; Byron, California; Liston et al. 1994, Fausch 2000); however, predation impacts to juvenile (20-40 mm) Delta Smelt (*Hypomesus transpacificus*) are not known. Results from Delta Smelt secondary screen efficiency experiments conducted without a predator removal event were compared to results from experiments conducted with a predator removal event to estimate the impact of Striped Bass (*Morone saxatilis*) predation on juvenile Delta Smelt in the fish bypass pipes and secondary channel. In one of the predator removal events, 21 of the 49 sub-adult Striped Bass (mean = 269 mm FL) stomachs contained juvenile Delta Smelt, suggesting Striped Bass negatively affect juvenile-sized Delta Smelt within the TFCF. Removal of Striped Bass from the bypass pipes and secondary channel significantly improved mean secondary channel traveling screen efficiency of juvenile Delta Smelt from 10.3% without predator removal to 50.2% with predator removal across the 5 secondary channel velocities tested (0.3, 0.46, 0.6, 0.76, and 0.9 m/s [1, 1.5, 2, 2.5, and 3 ft/s]). When Striped Bass were removed from the bypass pipes and secondary channel, secondary channel water velocity was a good predictor of secondary channel traveling screen efficiency with higher efficiencies measured at lower velocities.

15. SUBJECT TERMS
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Tracy Fish Facility Improvement Program
California-Great Basin · Interior Region 10

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Tracy Fish Facility Improvement Program

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Disclaimer

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Executive Summary

The Bureau of Reclamation (Reclamation) Tracy Fish Collection Facility (TFCF), part of the Central Valley Project (CVP), is located in the southern region of the Sacramento-San Joaquin River Delta (Delta) and was designed to salvage fish entrained in water exported from the Delta by the C.W. "Bill" Jones Pumping Plant. The TFCF uses a behavioral louver system in the primary channel, punctuated by four underground bypass pipes that lead to the secondary channel where a traveling fish screen guides fish into holding tanks. Fish are removed from the holding tanks daily and trucked to release sites approximately 30 km north near the confluence of the Sacramento and San Joaquin Rivers. The facility salvages close to 60 fish species, including the Delta Smelt (*Hypomesus transpacificus*), a species listed as endangered under the California Endangered Species Act and threatened under the Federal Endangered Species Act. Their decline in the Delta is part of a larger serious decline of pelagic fish species in the Delta. Although predation of adult Delta Smelt inside the TFCF has been studied (Bridges et al. 2019), predation of juvenile Delta Smelt within the TFCF has never been documented.

Striped Bass (*Morone saxatilis*), the facility's most prevalent predator, are found throughout the facility with smaller Striped Bass (sub-adult size: 150–300 mm) inhabiting the downstream components such as the secondary channel (Bridges et al. 2019). This size segregation of Striped Bass by location may be due to intraspecies competition and water velocity (Bridges et al. 2019). In other words, sub-adult Striped Bass inhabit this area because they cannot compete with larger Striped Bass upstream at the primary channel and the slower velocity in the secondary channel creates a refuge suitable for sub-adult Striped Bass. Striped Bass are the dominant predator (by biomass) in the secondary channel and are known to consume the most salvageable fishes in the TFCF (Sutphin et al. 2014). It is not known, however, how they affect juvenile Delta Smelt in the facility.

Mark-capture efficiency experiments were completed before and after secondary channel predator removals using carbon dioxide (CO_2). The first 8 releases without predator removal had low efficiency results with an average overall secondary screen efficiency of 10.3%. The inclusion of a predator removal improved the secondary screen efficiency to an average overall efficiency of 50.2 %. When predators were removed, the secondary channel velocity was a good predictor of traveling screen efficiency. Predator removal had greater positive impacts on traveling screen efficiency at slower secondary channel velocities of 1-2 ft/s.

Introduction

The Bureau of Reclamation (Reclamation) Tracy Fish Collection Facility (TFCF; Byron, California), a component of the Central Valley Project (CVP), is located at the head of the Delta-Mendota Canal intake channel in the southern region of the Sacramento-San Joaquin River Delta (Delta) near Tracy, California (Figure 1). The facility was designed to salvage small fish entrained in the water exported from the Delta by the C.W. "Bill" Jones Pumping Plant. Entrained fishes are diverted into one of four 15-cm-wide bypass pipe openings that transition into underground 0.9-m concrete fish bypass pipes leading to a secondary channel. In the secondary channel, fish encounter a 17-m-long traveling water screen angled 7° to the direction of water flow. Fish are then guided to another 15-cm-wide bypass which transitions into a 50.8-cm metal pipe that drains into a holding tank that is 6.1-m wide and 5.0-m deep. These collected or "salvaged" fish are removed from the holding tanks daily and trucked to release sites approximately 30 km north near the confluence of the Sacramento and San Joaquin Rivers where they are far from the influence of the south Delta pumping operations.

The components within the facility harbor piscivorous fish that can negatively affect salvage (Liston et al. 1994, Fausch 2000). Striped Bass (*Morone saxatilis*), the facility's primary predator, are found throughout the facility and are size segregated by location (Bridges et al. 2019, in press). Larger Striped Bass (>400 mm) inhabit the front of the facility and smaller, sub-adult Striped Bass (150–300 mm) are towards the downstream components such as the bypass pipes and secondary channel (Appendix A; Bridges et al. 2019, in press). These smaller Striped Bass are the dominant predator by biomass in the bypasses and secondary channel and consume the most salvageable fishes in the TFCF (Sutphin et al. 2014). It is not known, however, how they affect juvenile Delta Smelt (*Hypomesus transpacificus*; 20-40 mm), a species listed as endangered under the California Endangered Species Act and threatened under the Federal Endangered Species Act. The juvenile life stage of the Delta Smelt is observed at the TFCF in May and June. Juvenile Delta Smelt have been observed during the monitoring of Delta Smelt larvae at the TFCF, used to refine triggers for Actions in the Reasonable and Prudent Alternatives of the 2008 USFWS Biological Opinion. Their entrainment is of particular concern in dry years when the distribution of young fish shifts upstream and closer to the export pumps.

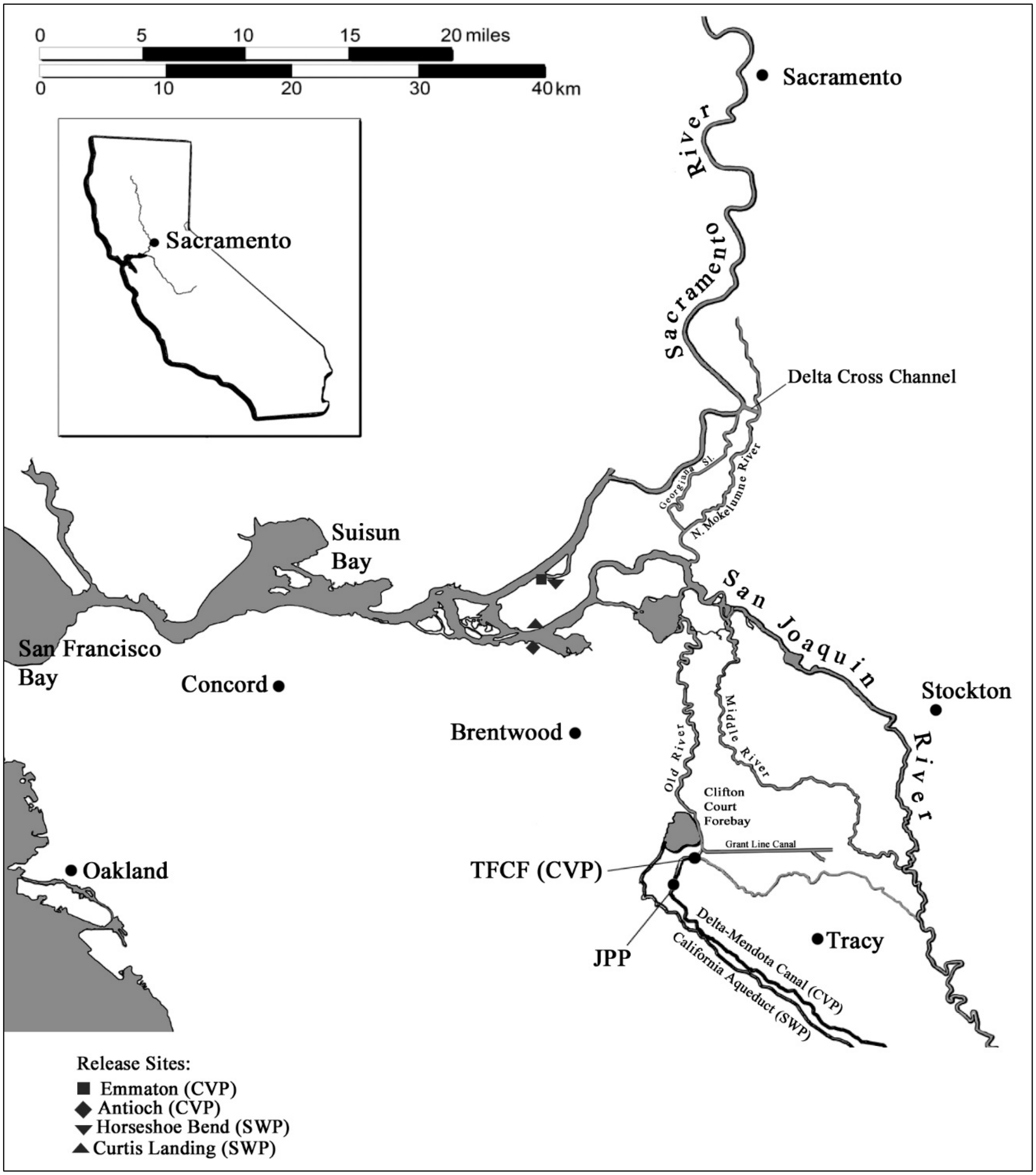

Figure 1.—Map of the Sacramento-San Joaquin Delta showing the location of the Tracy Fish Collection Facility (TFCF) and C.W. "Bill" Jones Pumping Plant (JPP) in the south Delta and the release sites located near the confluence of the Sacramento and San Joaquin Rivers. The Central Valley Project (CVP) is federally operated and the State Water Project (SWP) is operated by the State of California.

Methods

Pre-Release Procedures

Delta Smelt juveniles (20-40 mm FL) were transported from the UC Davis Fish Conservation and Culture Laboratory (FCCL) to the TFCF using 5-gallon black buckets (~100 fish per bucket) on the day of each test. Travel time and distance from FCCL to the TFCF was 4 minutes and 3.5 km, respectively. Because water was saturated with pure oxygen before the fish were added to the buckets and the fish at this life stage have low oxygen consumption, the dissolved oxygen level during transport remained at acceptable levels. Handling of juvenile Delta Smelt was kept at a minimum to limit stress and mortality. Instead of manually measuring and counting each fish which can be fatal at this life stage, groups of fish were photographed (Figure 2). Using a soft fine mesh net, fish were transferred from the black bucket into rectangular glassware (with 1-cm deep water) positioned on top of a light table. Water in the rectangular glassware was from the black bucket to limit temperature shock. A Canon EOS Rebel SL1 (18 MP resolution) camera on a tripod, a 60-mm macro lens, and a remote shutter were used for photographs. Shutter speed was 1/1250 at f/9.0 and 400 ISO. Photographed fish were counted and measured using Image-Pro 6.2 (Media Cybernetics, Inc., Rockville, Maryland). During the photography process, fish were mostly right side up; therefore, lengths were measured in mm total length (mm TL). Once fish were photographed, they were placed into an oxygen saturated black bucket where they remained until they were inserted into bypass pipe 4.

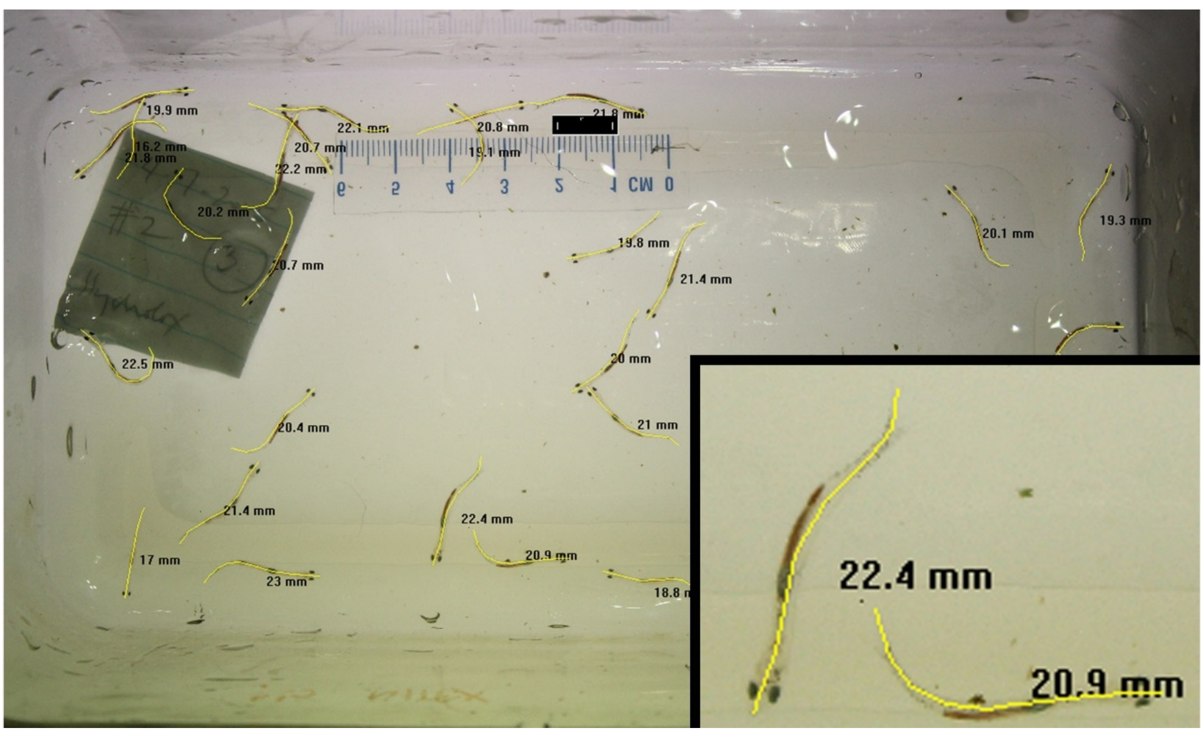

Figure 2.—Photograph of live juvenile Delta Smelt. An accurate count and measurement were obtained using Image-Pro 6.2 (right). Inset: enlarged image of Delta Smelt juveniles. Lengths are in mm TL.

Release Procedures

Juvenile Delta Smelt were released (100-300 fish/replicate) at the entrance of bypass pipe 4 (Figure 3) and entered the secondary channel at the set channel water velocity of 0.3, 0.45, 0.6, 0.76, and 0.9 m/s (1, 1.5, 2, 2.5, and 3 ft/s). All four panels of the Hydrolox™ traveling fish screen (traveling screen; Intralox, L.L.C., New Orleans, Louisiana) rotated simultaneously at a speed of 30.5 mm/sec (1.2 in/sec). The water velocity of the secondary channel was manipulated by the velocity control (VC) pumps located at the western terminal of the secondary channel. Fish lost through the traveling screen were not measured because the fine mesh sieve net installed behind the traveling screen was not available for the study.

Eight replicate releases (n = 1185) were completed in the absence of a predator removal (April 7–May 6, 2015), and 11 replicate releases (n = 2076) were completed following a predator removal (May 6–26, 2015; Appendix B). Since they were completed at different time periods, tests were not paired. Predators in the bypasses and secondary channel were removed using the CO_2 predator removal methodology developed by Wu and Bridges (2014). All predators from the first predator removal were euthanized and their stomachs dissected. The remaining replicates included a predator removal prior to fish releases, but did not include gut content analysis because the first predator removal was enough to show that predation occurred.

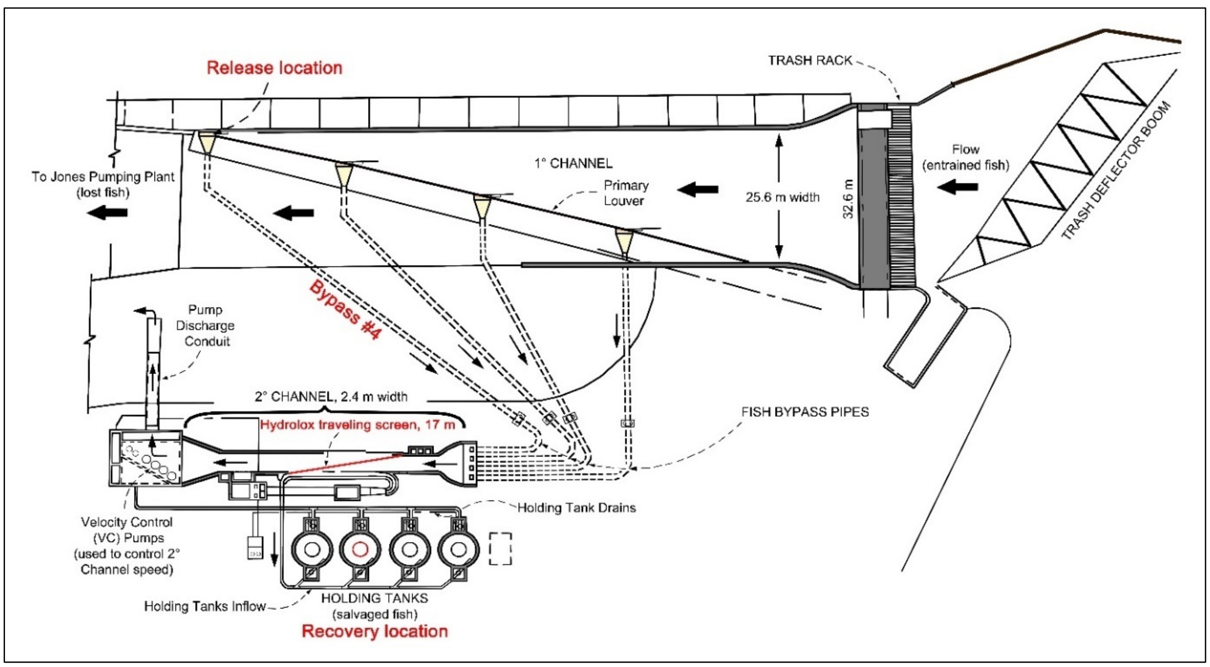

Figure 3.—Diagram of the Tracy Fish Collection Facility. In red are the release location, the fourth bypass pipe, Hydrolox™ traveling screen, and recovery location, holding tank 2.

Before test fish were released into bypass pipe 4, the secondary channel velocity was set. Velocities were chosen randomly. Fish were released into the bypass pipe 4 opening using a funnel (Figure 4, left). An additional bucket of water was used to wash down fish that may have adhered to the walls of the funnel. A cone-shaped 500-µm fine mesh larval sieve net was installed at the drain of the holding tank to collect all test fish that made it to the holding tank. Holding tank flows were adjusted to keep the bypass ratio (velocity of water going to the holding tank : velocity of water in secondary channel) above one. Fifteen minutes after the release, the cone-shaped sieve net was lifted from the holding tank with a hoist. Fifteen minutes was deemed sufficient because the travel time for a particle going 1 ft/s (0.3 m/sec) from point of release to the holding tank, a distance of about 460 ft (140 m), is 7.7 minutes. Fish that may have adhered to the cone-shaped sieve net were sprayed into a bucket (Figure 4, right). Fish loss during recovery process was assumed to be similar across all replicates.

Figure 4.—Release and recovery of juvenile Delta Smelt. A funnel and tube were used to insert fish (left) into bypass pipe 4. White arrow indicates direction of flow. Fish were recovered from the holding tank using a cone-shaped 500-µm fine mesh larval sieve net and concentrated into a bucket (right).

Post-Release Procedures

All juvenile fish recovered in the holding tank were preserved with 10% formalin solution, stained with Rose Bengal, photographed, and measured using Image-Pro 6.2 imaging analysis software (Figure 5). Test fish were differentiated from wild osmerid and non-osmerid fish using Wang (1986) and Reyes (2019, in draft).

The secondary channel traveling screen efficiency is calculated by:

$$E_{screen} = (H + H_{SN})/I_{BP4}, \quad \text{(Eq. 1)}$$

where:
E_{screen} = efficiency of secondary channel traveling screen,
H = number of fish retained by the holding tank screen,
H_{SN} = number of fish recovered in the sieve net in the holding tank drain, and
I_{BP4} = number of fish inserted in bypass pipe 4.

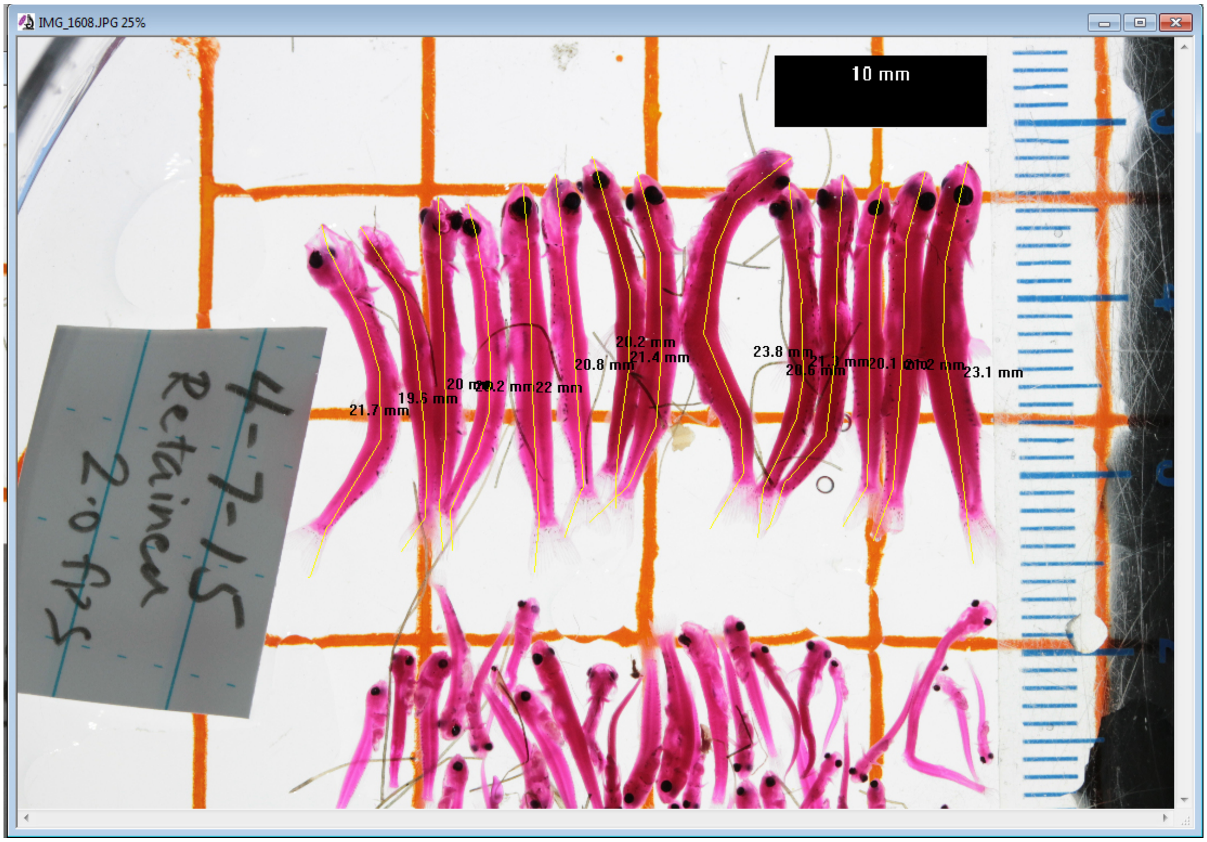

Figure 5.—Recovered juvenile Delta Smelt preserved with 10% formalin solution, stained with Rose Bengal, photographed, and measured with Image-Pro 6.2 imaging analysis software. Lengths are in mm TL. The non-measured fish were wild bycatch.

Data Analysis and Interpretation

To test the difference in Delta Smelt lengths before and after predator removal, non-parametric Kruskal-Wallis one-way ANOVA on Ranks was used. Multiple Linear Regression Analysis was used to analyze the effects of fish lengths on secondary channel traveling screen efficiency and the effects of velocity on secondary channel traveling screen efficiency within the two experimental conditions. To see if there was a difference between the two experimental conditions (before and after predator removal) and secondary channel velocity, Two-way ANOVA on Ranks was used. All statistical analyses were completed using SigmaStat 3.5 (Systat Software, Inc., Chicago, Illinois).

Results and Discussion

A total of 3,261 Delta Smelt (range: 12.7–48.3 mm TL, average: 24 mm TL) were released in the study: 1,185 fish (8 replicates; 100-300/replicate) were released without removing the predators and 2,076 fish (11 replicates; 100-200/replicate) were released after removing the predators. The predator removal events improved the average secondary channel traveling screen efficiency from 10.3% to 50.2% (Appendix B). Even with predator removal, however, low efficiencies were observed during high secondary channel velocities of 2.5 and 3.0 ft/s (Appendix C). The high number of unaccounted fish which negatively affected the efficiency were likely from fish lost through the secondary channel traveling screen. Tests completed in 2016, not presented in this paper, suggest that this may be the case at higher velocities.

To verify predation on juvenile Delta Smelt, 49 Striped Bass (mean length=269 mm, SD=45 mm) from a predator removal event were analyzed for stomach content. Of the 49 Striped Bass removed, 21 had test fish in their stomach, four consumed nine or more test fish, and a total of 89 (45%) were consumed (Appendix D). Four White Catfish (*Ameiurus catus*), also a common piscivore at the TFCF, were removed and none had test fish in their stomach.

There were significant differences in the median lengths of fish released at bypass pipe 4 for the majority of replicate releases ($P<0.050$; Figure 6). Although we attempted to release fish that were in the early juvenile size range of 20-25 mm TL, fish used for the study had a wide size range. Fish used for the releases without predator removal were smaller than the fish used with predator removal. This was expected since the replicates without predator removal were done earlier in the Delta Smelt culture process, i.e., fish obtained from the FCCL were younger and smaller.

Since fish used for the two treatments had significant difference in median lengths, there was a possibility that the two data sets were not comparable. However, the difference in fish size may be minor since there does not seem to be size effect on traveling screen efficiency within the range of sizes tested (Figure 7). Fish length in general was not a good predictor of secondary channel traveling screen efficiency with or without predator removal.

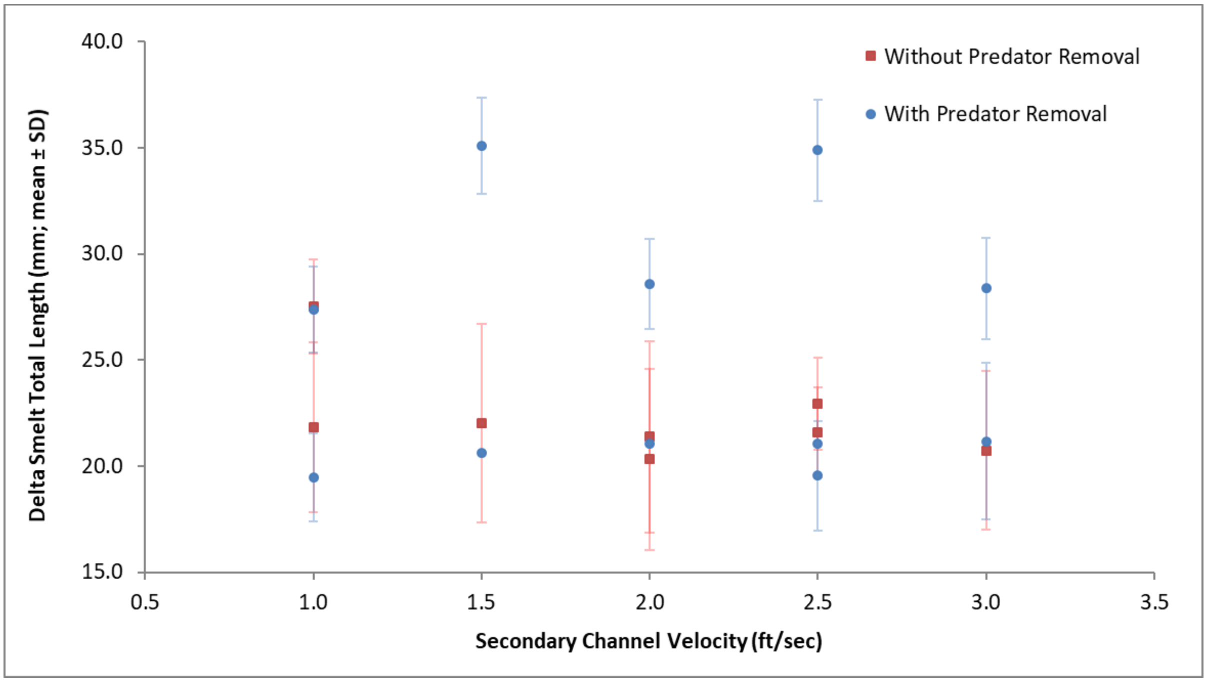

Figure 6.— Mean (± 1 SD) total length of juvenile Delta Smelt released into bypass pipe 4 at different secondary channel velocities without (red squares) and with (blue circles) predator removal efforts. Fish used for the test with predator removal were significantly larger than fish used for the test without predator removal.

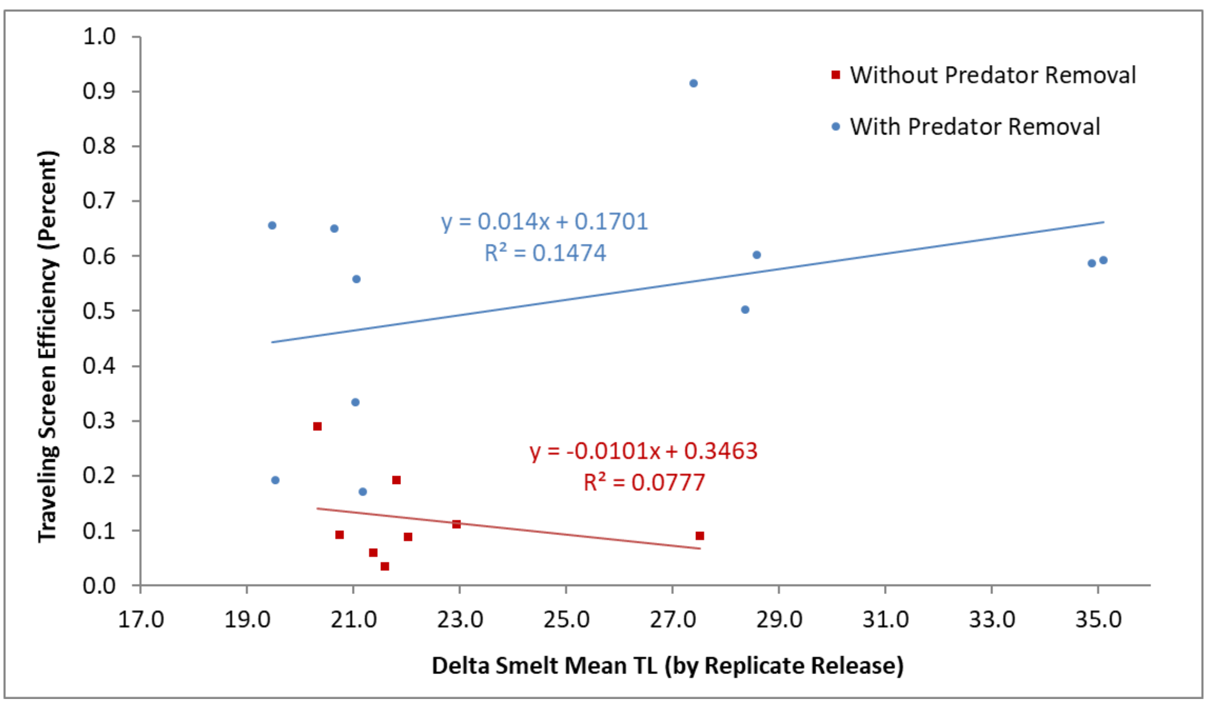

Figure 7.—Effects of juvenile Delta Smelt mean length on secondary channel traveling screen efficiency. Fish size was not a good predictor of efficiency.

Simple linear regression was used to visualize the differences between the two testing conditions (Figure 8). The data without predator removal did not fit the regression model (R^2=0.06). In general, regardless of velocity, secondary channel traveling screen efficiency was low and predicting the correlation between efficiency and velocity was difficult if predators were not removed. The removal of predators produced a better linear model (R^2=0.61), suggesting that with increased velocity, secondary channel traveling screen efficiency decreased. When predators were removed, secondary channel velocity was a good predictor of traveling screen efficiency.

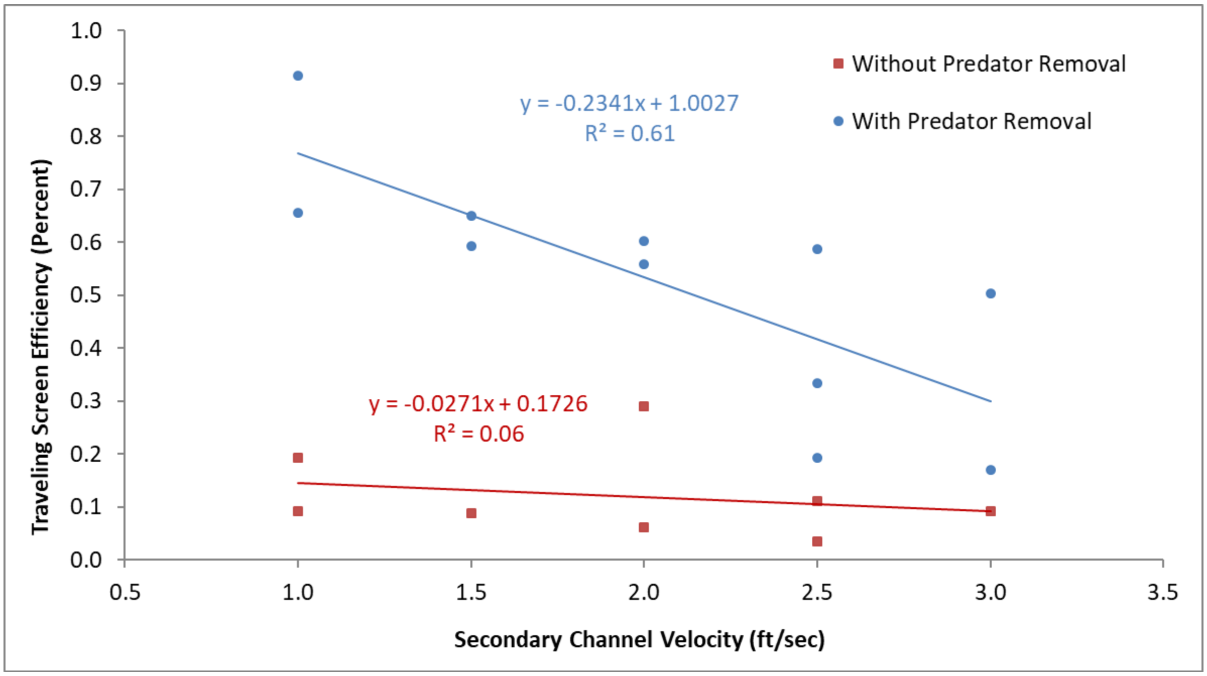

Figure 8.—Effects of secondary channel velocity on secondary channel traveling screen efficiency of juvenile Delta Smelt. Secondary channel velocity was a good predictor of traveling screen efficiency when predators were removed.

There was a significant difference between the two experimental conditions at each secondary channel velocity category using Two-Way ANOVA on Ranks (Power for velocity = 0.170; Power for experimental condition = 0.999; Figure 9). At each velocity category, efficiency was better without predators. Predator removal has greater positive impacts at the slower speeds of 1-2 ft/s which are the preferred velocities for increased salvage efficiency of larval and juvenile fish (Reyes n.d., unpublished data). It is at these speeds that a predator removal would be most beneficial for juvenile Delta Smelt. Since larval and juvenile fish in general are relatively weak swimmers, slower water velocities allow these fish to hold within the water column, limiting the likelihood of getting impinged against or getting lost through the screens, and increasing the chances of being diverted to a holding tank. At faster velocities, positive impacts to efficiency from predator removal is noticeable but the efficiency is also negatively impacted by the loss through the traveling screens.

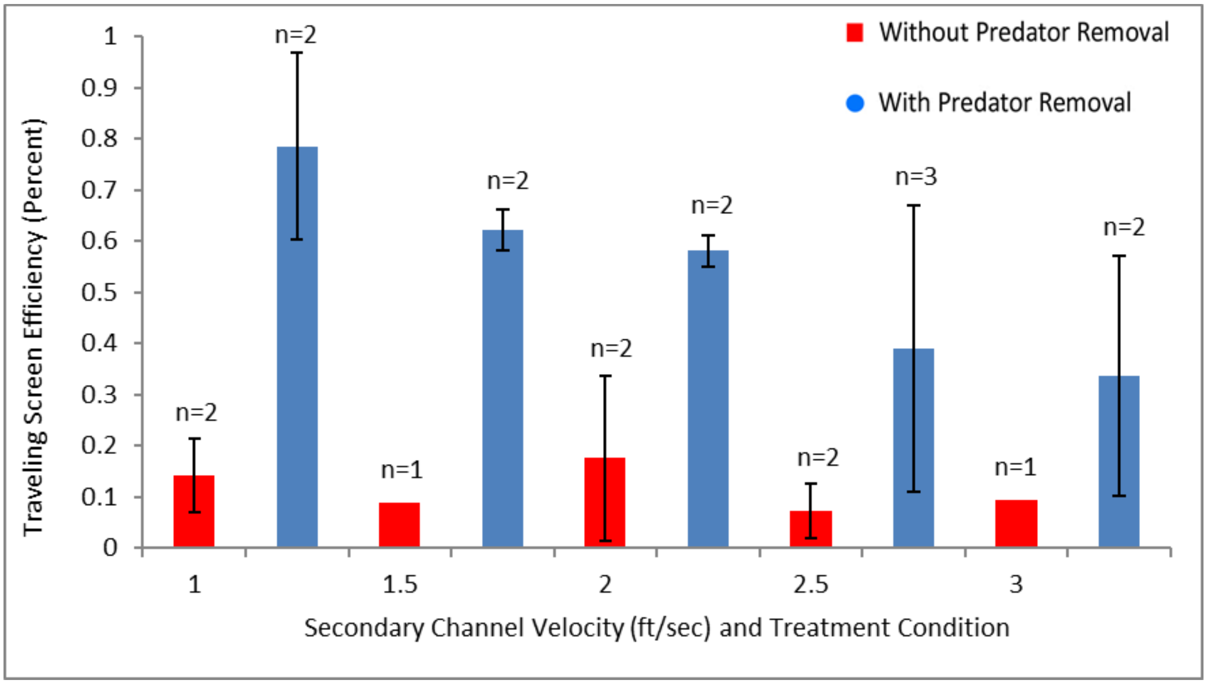

Figure 9.—Mean (± 1 SD) secondary channel traveling screen efficiency of juvenile Delta Smelt before (red bars) and after (blue bars) predator removal at five different secondary channel velocity categories, before vs. after removal (Two-Way ANOVA on Ranks [P < 0.001]). Traveling screen efficiency was better across all velocities tested when predators were removed.

Recommendations

Predation on entrained fish has been reported for adult Delta Smelt and juvenile Chinook Salmon (Bridges et al. 2019, in press), and the current study indicates juvenile Delta Smelt can also be impacted. Even though juvenile Delta Smelt are tiny and translucent, Striped Bass are able to detect and prey on them. CO_2 has been proven to be an effective tool for removing predators within the facility (Wu and Bridges 2014) and is already implemented on a monthly basis for the bypass pipes and secondary channel at the TFCF. We recommend the continuous use of this technique, perhaps with increased frequency of application, to improve the salvage of larval and juvenile fish during the Delta Smelt larval season. A combination of predator removal and slower secondary channel velocities (1-2 ft/s) during the months when larval and juvenile Delta Smelt are present should be considered. Historically, salvage of juvenile Delta Smelt and juvenile Chinook Salmon is highest in May which is within the operational criteria for Chinook Salmon (Salmon criteria of 3-3.5 ft/s for the secondary channel from Feb. 1–May 31, SWRCB D-1485). Therefore, an adaptive management strategy for the operation of the secondary channel may be necessary to resolve the conflicting requirements of the two listed species.

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Appendix A—Size Segregation of Striped Bass Within the Tracy Fish Collection Facility

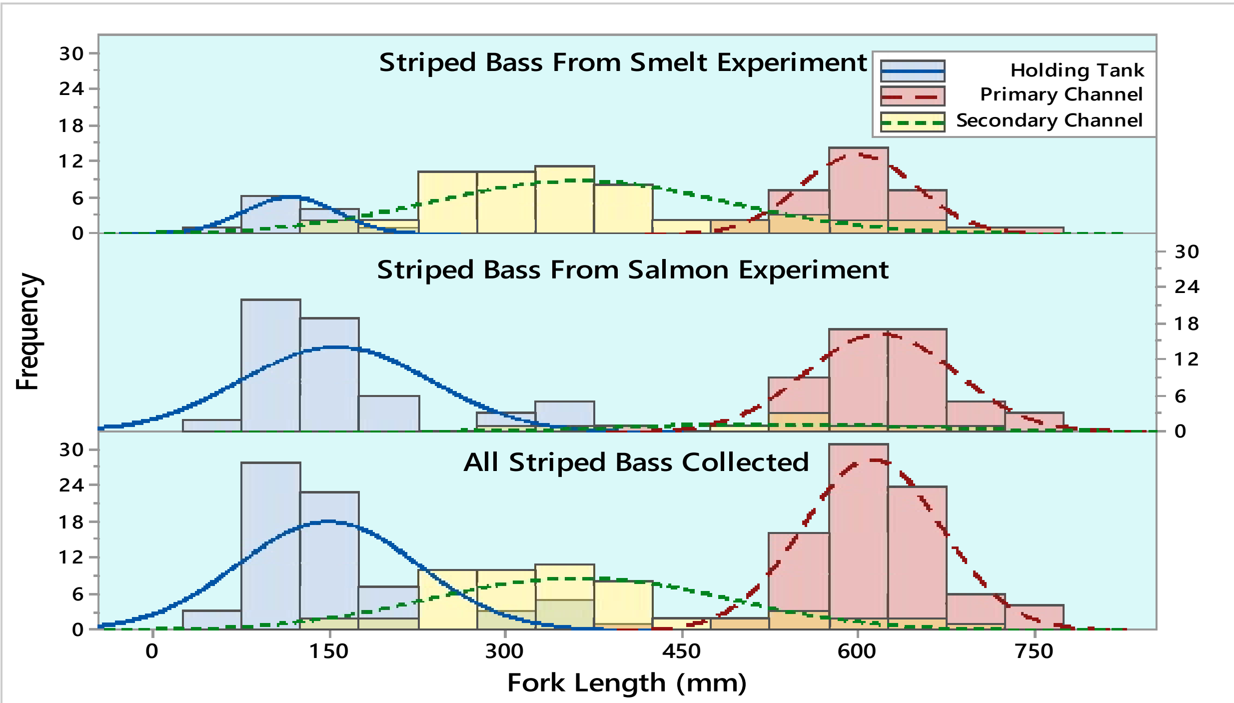

Figure A-1.—Size segregation of Striped Bass within the Tracy Fish Collection Facility (from Bridges et al. 2019, in press) showing 150-300 mm Striped Bass (yellow bars) residing within the secondary channel. Note: secondary channel includes the bypass pipes.

Appendix B—Summary of traveling screen efficiency at various secondary channel velocities at the Tracy Fish Collection Facility

Table B-1.—Summary of traveling screen efficiency at various secondary channel velocities at the Tracy Fish Collection Facility. Tests were conducted without CO2 predator removal from April 7–May 6, 2015 and with CO2 predator removal from May 6–26, 2015. Efficiencies from tests with CO2 predator removal are in bold and show significant improvement.

Secondary Velocity (ft/s)	1	1	1.5	1.5	2	2	2.5	2.5	3	3	Overall	Overall
CO_2 Treatment Before Release	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Number of Releases	2	2	1	2	2	2	2	3	1	2	8	11
Number of Fish Released	198	291	296	396	297	391	297	598	97	400	1185	2076
Average Length of Fish Released (mm)	24.7	23.4	22	27.9	20.8	24.8	22.3	25.2	20.7	24.8	22.3	25.2
Number of Fish Diverted	28	215	26	246	41	227	18	222	9	133	122	1043
Average Length of Fish Diverted (mm)	23.2	21.4	20.6	27.1	20.2	25.8	23.1	24.4	22.6	25.6	21.9	25.2
Efficiency (%)	14.1	**73.9**	8.8	**62.1**	13.8	**58**	6.1	**37.1**	9.3	**33.3**	10.3	**50.2**

Appendix C—Secondary Channel Hydrolox™ Traveling Screen Efficiency for Juvenile Delta Smelt when Predators Are Present and Absent

Table C-1.—Secondary channel Hydrolox™ traveling screen efficiency for juvenile Delta Smelt when predators are present (i.e., Without predator removal [PR]) and when they are absent (i.e., With PR).

Date	Condition	Vel (ft/sec)	I_{BP4}	H	H_{SN}	Hydrolox Conveyer Belt	Unaccounted	Traveling Screen Efficiency
4/7/2015	Without PR	3	97	8	1	0	88	9.3%
4/7/2015	Without PR	2	100	16	13	0	71	29.0%
4/10/2015	Without PR	1	99	19	0	0	80	19.2%
4/10/2015	Without PR	2.5	198	5	2	0	191	3.5%
4/10/2015	Without PR	1.5	296	15	11	0	270	8.8%
4/10/2015	Without PR	2	197	6	6	0	185	6.1%
4/13/2015	Without PR	2.5	99	5	6	0	88	11.1%
5/6/2015	Without PR	1	99	7	2	0	90	9.1%
5/6/2015	With PR	1	93	77	8	0	8	91.4%
5/7/2015	With PR	2	194	99	18	0	77	60.3%
5/7/2015	With PR	3	195	68	30	5	92	50.3%
5/20/2015	With PR	2.5	198	31	7	0	160	19.2%
5/22/2015	With PR	2.5	199	117	0	0	82	58.8%
5/22/2015	With PR	1.5	199	115	3	10	71	59.3%
5/22/2015	With PR	1	198	87	43	0	68	65.7%
5/26/2015	With PR	3	205	18	17	1	169	17.1%
5/26/2015	With PR	1.5	197	113	15	0	69	65.0%
5/26/2015	With PR	2	197	110	0	1	86	55.8%
5/26/2015	With PR	2.5	201	67	0	1	133	33.3%

I_{BP4} = number of fish inserted into bypass pipe 4.
H = number of fish retained by the holding tank screen.
H_{SN} = number of fish recovered in the sieve net in the holding tank drain.
Hydrolox Conveyer Belt = number of fish impinged by the traveling screen and recovered at the conveyer belt.
Unaccounted = number of fish lost through the traveling screen or predation.

Appendix D—Gut Content of Predators Removed from a Single Predator Removal Event at the Tracy Fish Collection Facility

Table D-1.—Gut content of predators removed from a single predator removal event on May 6, 2015, at the Tracy Fish Collection Facility. Delta Smelt juvenile (n=200) were inserted before the predator removal event.

		Predator Stomach Content	Predator Stomach Content	Predator Stomach Content	
Predator	Length (mm)	Delta Smelt	Prickly Sculpin	Striped Bass	Unidentified
Striped Bass	288				
Striped Bass	332	2			
Striped Bass	174	1			
Striped Bass	223		1		
Striped Bass	287	1			
Striped Bass	251	10			
Striped Bass	270		2		
Striped Bass	340	2			
Striped Bass	330		1		
Striped Bass	224	3			
Striped Bass	280				
Striped Bass	257				
Striped Bass	309	3			
Striped Bass	301				
Striped Bass	280	1			
Striped Bass	355				
Striped Bass	171			1	
Striped Bass	267				
Striped Bass	272				
Striped Bass	302	9			
Striped Bass	230	7			
Striped Bass	234				
Striped Bass	323				
Striped Bass	335				
Striped Bass	250				
Striped Bass	262	2			
Striped Bass	219	3			1
Striped Bass	236	3			
Striped Bass	214				1
Striped Bass	221	4			
Striped Bass	208	1			1
Striped Bass	290	2			

		Predator Stomach Content	Predator Stomach Content	Predator Stomach Content	
Predator	**Length (mm)**	**Delta Smelt**	**Prickly Sculpin**	**Striped Bass**	**Unidentified**
Striped Bass	296				
Striped Bass	264				
Striped Bass	279	2			
Striped Bass	300				
Striped Bass	263				
Striped Bass	219				
Striped Bass	338	12			
Striped Bass	318				
Striped Bass	253				
Striped Bass	242	12			
Striped Bass	255	7			
Striped Bass	222				
Striped Bass	357				
Striped Bass	210	2			
Striped Bass	303				
Striped Bass	280				
Striped Bass	262				1
White Catfish	149				
White Catfish	113				
White Catfish	259				
White Catfish	104				
	TOTAL	**89**	**4**	**1**	**4**